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A Real-Time Application of the ADCIRC-2DDI Hydrodynamic Model at Camp Pendleton, California

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A real-time ADCIRC finite element hydrodynamic model is applied in support of the Joint Forces Exercise (JTFEX) off the coast of southern California 16–23 Jul 1997. A modeling strategy is designed for Camp Pendleton coastal waters and appropriate sensitivity analyses are conducted to assess initial model performance. The real-time modeling framework comprises automation of the model setup, execution, post-processing, visualization, and an interactive World Wide Web interface. Performance of the real-time ADCIRC application, including computational and manual efforts during the JTFEX, is assessed. Model computed 24-h forecasts for sea surface height during periods of light winds compare favorably with observed water levels. Several suggested improvements to the real-time forecast capability include more appropriate boundary specifications for wind-driven flow, a model restart option, and tools for merging multiple resolution data sources. The JTFEX exercise enabled transition of an ADCIRC real-time forecast system to the U.S. Naval Oceanographic Office and provided insight into operational needs and issues.

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EXECUTIVE SUMMARY

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A REAL-TIME APPLICATION OF THE ADCIRC-2DDI HYDRODYNAMIC MODEL AT CAMP PENDLETON, CALIFORNIA

1.0 INTRODUCTION

1.1 Exercise Description

During the period of 14–25 Jul 1997, the Ocean Dynamics and Prediction Branch (Code 7320) of the Oceanography Division at the Naval Research Laboratory (NRL) participated in a Joint Forces Exercise (JTFEX) located off the coast of southern California. The purpose of NRL's participation was to implement, test, and showcase current research capabilities that can, in the near future, enhance or improve existing operational forecast capabilities of the Navy.

The JTFEX exercise encompassed a region from Point Conception, CA, to San Clemente Island, down to San Diego, CA, and extended 50 mi offshore from the beach. The inshore area of primary focus is defined by Oceanside Harbor and a stretch approximately 5 mi north of Oceanside to nearly 10 mi offshore. Contained within this region are three beaches identified for specific naval operations: red (for amphibious landing), white (for SEAL operations), and blue (for mine warfare activities); each beach is approximately 1 mi long. The exercise began in deep, offshore waters on 14 Jul and commenced with a beach landing early morning on 23 Jul 1997.

1.2 Goals of the Real-Time ADCIRC Model

The environmental variables produced by the ADCIRC-2DDI hydrodynamic model include sea surface height and depth-integrated currents. Spatial coverage for these model products is limited by the bounds of the finite element computational mesh. The mesh constructed for the California coastal waters centers on the Southern California Bight, but ranges along the coast from San Francisco, CA, to just north of Baja California, Mexico, and extends seaward beyond the shelf break. Model products for the purpose of the JTFEX, however, are restricted to those areas both offshore and inshore defined by the exercise as detailed above.

The goals of participation involve daily execution of the ADCIRC-2DDI hydrodynamic model for the purpose of providing 48-h forecasts of sea surface height and current conditions at locations within the exercise region. These model products are to be displayed in a user-friendly format on the World Wide Web (WWW). Since the model products are derived from the research environment and are perhaps new to the Navy user, a portion of the WWW interface is devoted to educating the user about the model, as well as detailing specifics of the model configuration that influence the model product. The forecasts described could be executed manually via the ADCIRC model each day; this scenario is undesirable due to time constraints in the research environment and because ultimately the goal is to develop automated modeling systems that will transition to the operational Navy.

As preparation for support of the JTFEX, the setup, execution, post-processing of results, and visual display of model products to the WWW are to be as fully automated as possible. A great challenge is presented in this task as the ADCIRC model has neither been exercised in a real-time fashion for the Navy nor has its complete setup and post-processing been fully automated at any prior time. Clearly, the JTFEX serves both as an opportunity to develop a real-time forecast capability using the ADCIRC-2DDI model and as a test of that functionality. Furthermore, through this exercise, steps necessary to ensure reliable and accurate forecasts within a rapid response framework are identified and an opportunity to evaluate the automated, rapid response capability is provided. Lastly, a more complete understanding of the issues involved in a real-time operation as gained from this exercise can be applied to future research or model enhancements.

2.0 THE FORECAST MODEL

2.1 The ADCIRC-2DDI Hydrodynamic Model

The finite element-based hydrodynamic model, ADCIRC-2DDI (Luettich et al. 1992) is implemented for the JTFEX operational exercise, 14–24 Jul 1997. ADCIRC-2DDI is the depth-integrated option of a system of two- and three-dimensional hydrodynamic codes. The models are based on the Generalized Wave-Continuity Equation solved in conjunction with the primitive form of the momentum equations. Governing equations reflect an assumption of incompressibility, as well as the Boussinesq and hydrostatic pressure approximations. The model has the capability of wetting and drying computational cells and uses the standard quadratic parameterization for bottom stress.

Accuracy of ADCIRC tidal and storm surge simulations are due in great part to the inherent flexibility of an unstructured computational grid. This capability facilitates the use of a large model domain and is considered an ideal formulation for both tidal and storm surge simulations (Luettich and Westerink 1995; Blain et al. 1994). For example, flexibility of the finite element method leads to easy incorporation of coastline detail and nodal densities that can range from three to four orders of magnitude in spatial resolution. This wide variation in nodal density arises from hydrodynamic considerations of tides and surges propagating from deep, open water to the coastal zone (Blain et al. 1998; Westerink et al. 1994b).

Full details regarding the model formulation are found in Luettich et al. (1992); a descriptive User's Guide is provided by Westerink et al. (1994a). In addition, a validation and sensitivity study characterizing the ADCIRC-2DDI model performance with regard to tidal dynamics and prediction is given by Blain and Rogers (1998).

2.2 Model Setup

2.2.1 Model Domain and Finite Element Mesh

The model domain selected includes the California coast from north of San Francisco down to the northern portion of Baja California, Mexico, and extends off the continental shelf into deep Pacific Ocean waters to a maximum longitude of 126.5° W (Fig. 1). Camp Pendleton, CA, is at the center of the domain coastline. Discretization of the domain is achieved using variably graded, finite elements. The base mesh is identical to the SOCAL (Southern California) mesh currently in use at the U.S. Naval Oceanographic Office (NAVOCEANO). The finest resolution in the SOCAL finite element grid is 1.2 km surrounding Camp Pendleton, CA. In offshore regions, the mesh

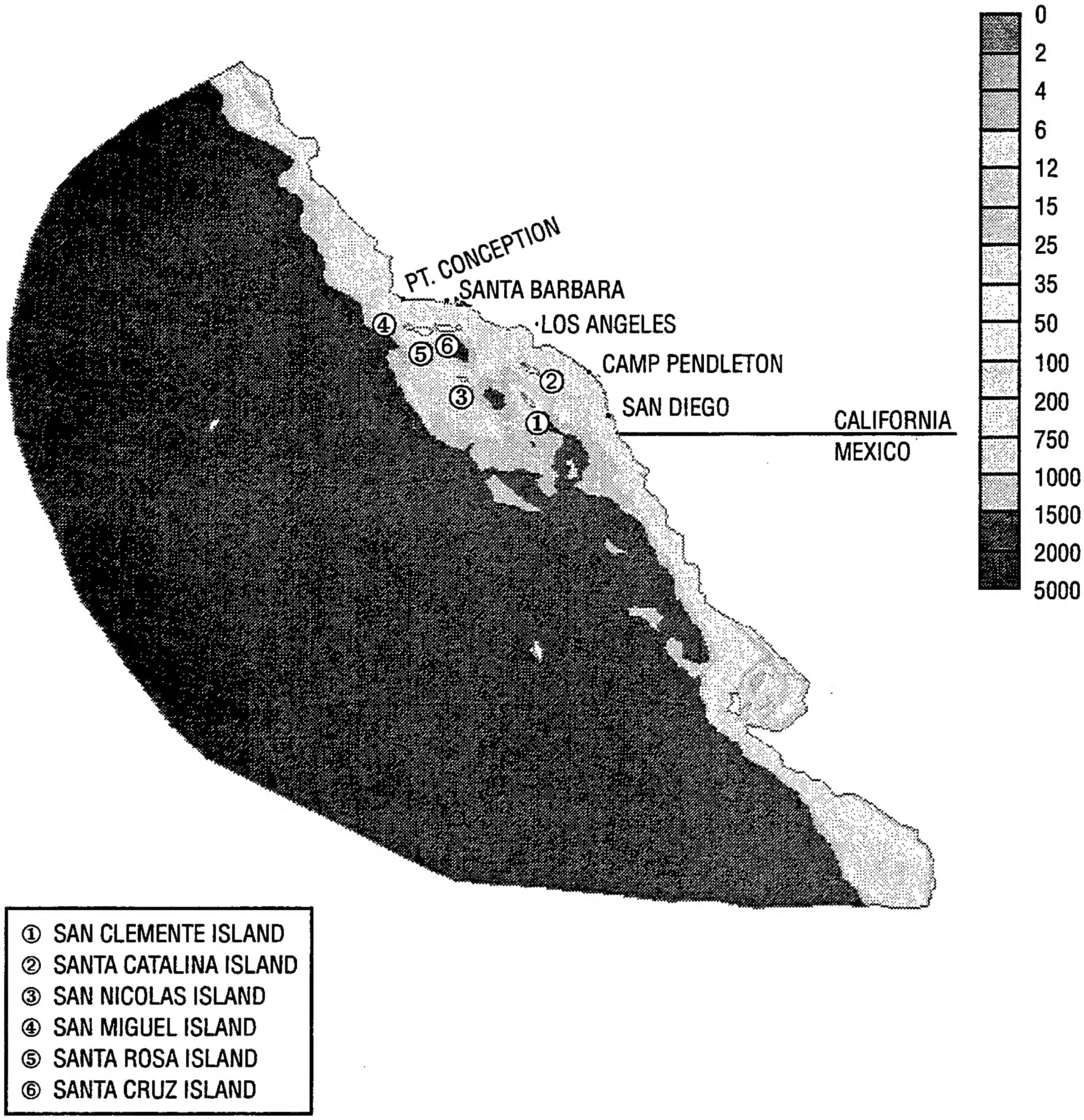

Fig. 1 — The Camp Pendleton (CAMPP) ADCIRC model domain

extends beyond the continental shelf break into Pacific waters whose depths are greater than 2000 m. In these deep waters, nodal spacing coarsens to a maximum of 78 km. The base SOCAL mesh has been further refined to achieve 0.5-km resolution in and around Oceanside Harbor, CA, which contains the three landing beaches for the JTFEX (see Fig. 2 for contours of mesh resolution). This refined finite element mesh, the CAMPP (Camp Pendleton) grid, remains relatively small in size with only 6108 nodal points (Fig. 3a and b).

In addition to increasing the mesh resolution in a localized area along the coast, the bathymetry for the mesh is updated to include the recently released 1-minute DBDB-V bathymetric data base for the U.S. West Coast (Naval Oceanographic Office 1996). The DBDB-V data is linearly interpolated onto the refined finite element mesh, replacing the DBDB-5 5-min resolution bathymetry in overlapping regions (Fig. 4a). Only the crudest form of insertion was implemented in merging these two bathymetric sources over the finite element mesh. A more sophisticated and automated means for

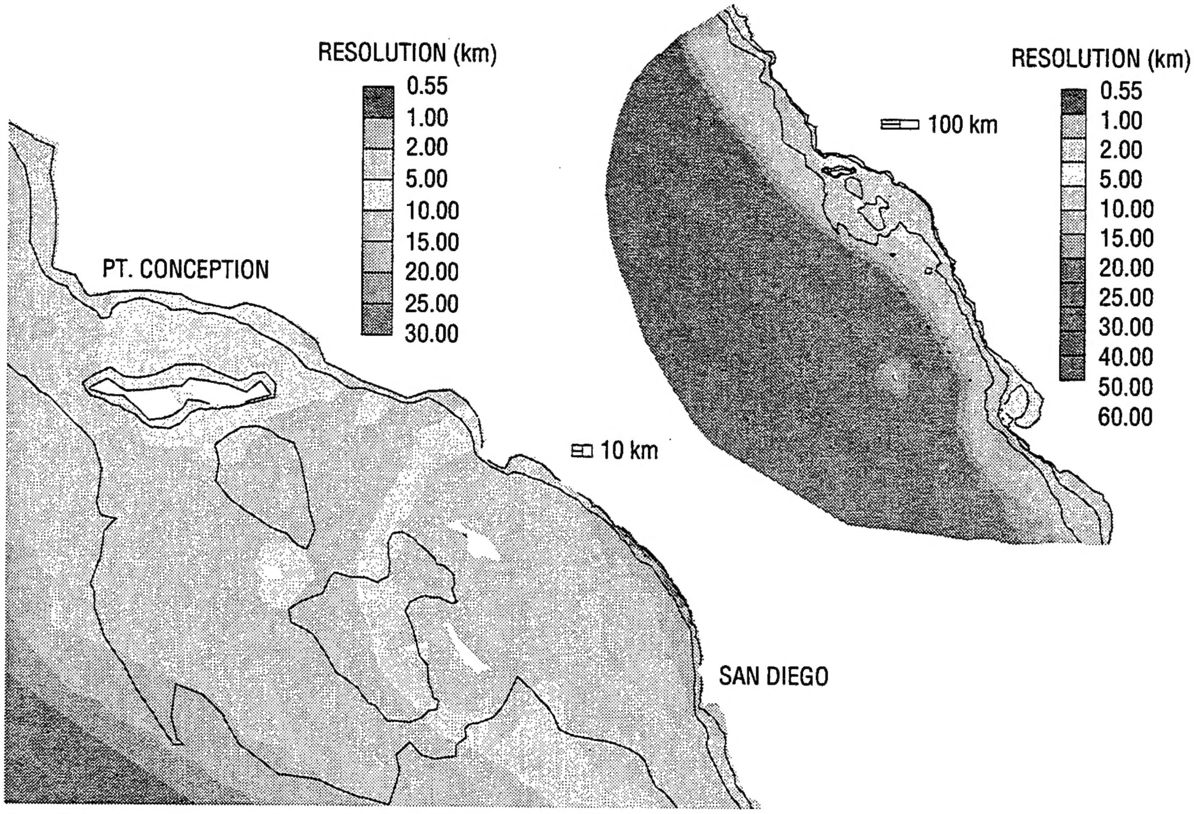

Fig. 2 — Contours of finite element mesh resolution for the CAMPP model domain. Overlaid in black are the 10, 100, and 1000 m bathymetric contours.

merging topographic data from varied sources is clearly needed, especially in the context of a rapid response exercise. Discrepancies between bathymetric data coastlines and the coastal outlines from shoreline data bases create inconsistencies at the shoreward extremes of the mesh (Fig. 4b). Discontinuities between the topography and the shoreline ultimately degrade the forecast capability of the model in these very nearshore areas.

2.2.2 Forcing

Forcing for the ADCIRC-2DDI model includes surface pressure, surface wind stress, tidal forcing at the open ocean boundaries, and forcing interior to the domain through the tidal potential. The tidal constituents specified for forcing are equilibrium values and can be obtained a priori. The tidal factors and phase corrections for each constituent are, however, date dependent. Furthermore, data sources for surface pressure and wind stress are obviously specific to the time period of the exercise and must be obtained on a real-time basis.

Atmospheric surface pressure and wind velocity components are taken from the Pt. Mugu Navy Operational Regional Atmospheric Prediction System (NORAPS) Fleet Numerical Meteorology and Oceanography Command (FNMOC) operational product (Baylor and Lewit 1992; Hodur 1982). The NORAPS fields are derived from data assimilative, mesoscale atmospheric model forecasts computed over a 0.2 horizontal square grid centered at Pt. Mugu, CA, shown in Fig. 5. Spatial coverage of this data base falls short of including the entire CAMPP model domain along the far western

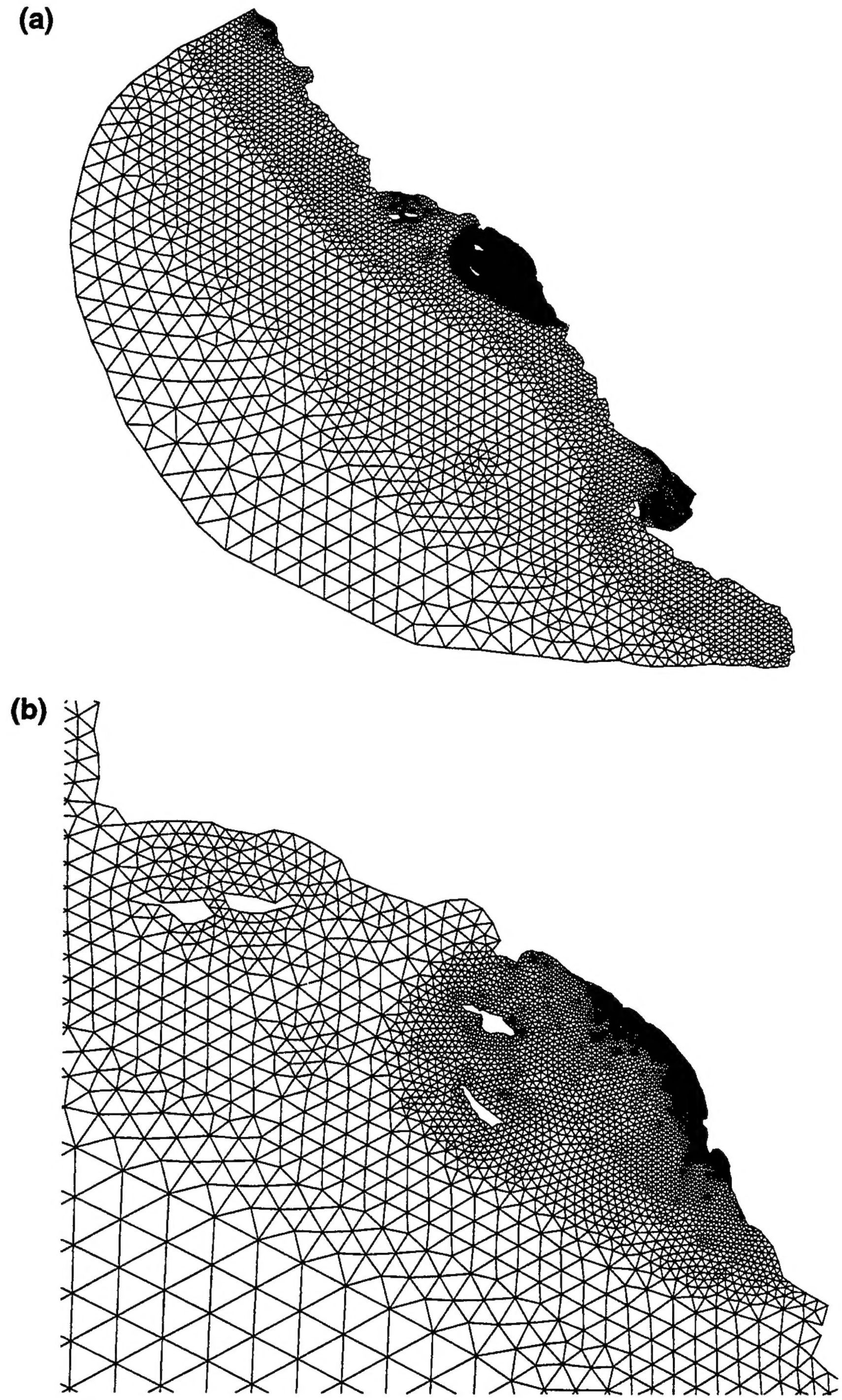

Fig. 3 — Finite element discretization of (a) the entire CAMPP model domain and (b) a close-up of the JTFEX exercise location

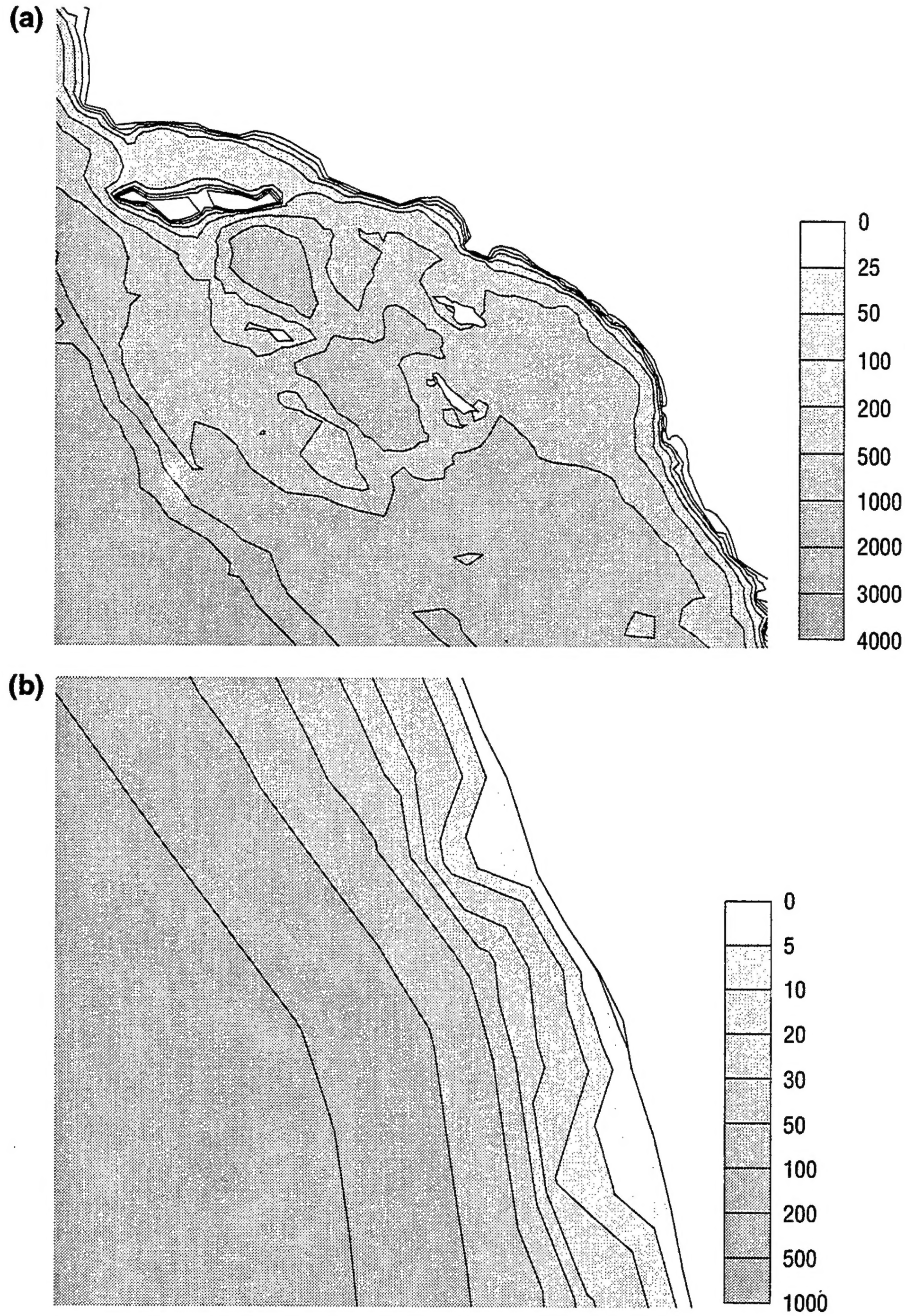

Fig. 4 — (a) DBDB-V bathymetry interpolated to the CAMPP mesh in the region of the JTFEX exercise and (b) discrepancies between the World Vector Shoreline data base and the DBDB-V coastline at Camp Pendleton, CA

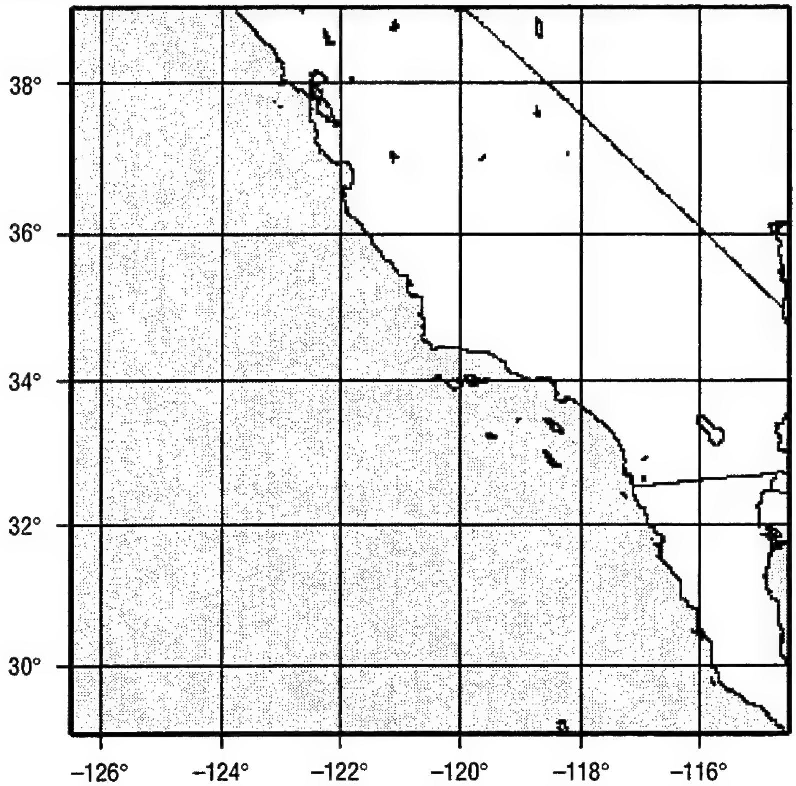

Fig. 5 — FNMOC NORAPS Pt. Mugu 0.2° resolution mesh for surface wind and pressure forcing

boundary and in the extreme southeastern corner. As for bathymetry, no readily available approach exists to combine data sources, especially of those of differing resolutions. So, for portions of the domain that lie outside of the Pt. Mugu NORAPS data (i.e., east of 114.5° W longitude and the southeastern corner of the mesh), wind velocity and surface pressures are assumed uniform with values assigned from the nearest neighbor points that fall just inside the NORAPS grid. Clearly, model predictions in the local vicinity east of 114.5° will be unreliable. However, it is thought that this region is far enough removed from the primary exercise location that the forecasts of interest will be unaffected by this alteration of the forcing. The modification to forcing in the southeast corner of the domain results in problematic local forecasts for the surrounding area. Again, the need arises for an automated means of merging various wind products to fully and seamlessly cover a defined spatial region of model application.

Tidal forcing for the operational forecasts is generated from an ADCIRC-2DDI model simulation of the eastern Pacific Ocean. The smaller CAMPP domain has its open boundary situated across the steep continental slope in shoreward reaches of the Pacific waters; these boundaries are not ideally placed for direct forcing by tidal elevations derived from a global tidal model. The eastern Pacific simulation uses a large mesh (27,702 nodes) that covers the eastern Pacific Ocean (Fig. 6) at a resolution that is considerably coarser inshore (~2.6 km) than the CAMPP mesh; forcing for this large mesh consists of tidal amplitudes and phases for six constituents (M_2, S_2, N_2, K_2, K_1, O_1) from the Grenoble Global tidal model (LeProvost 1994). Harmonic analysis of a 215-d simulation

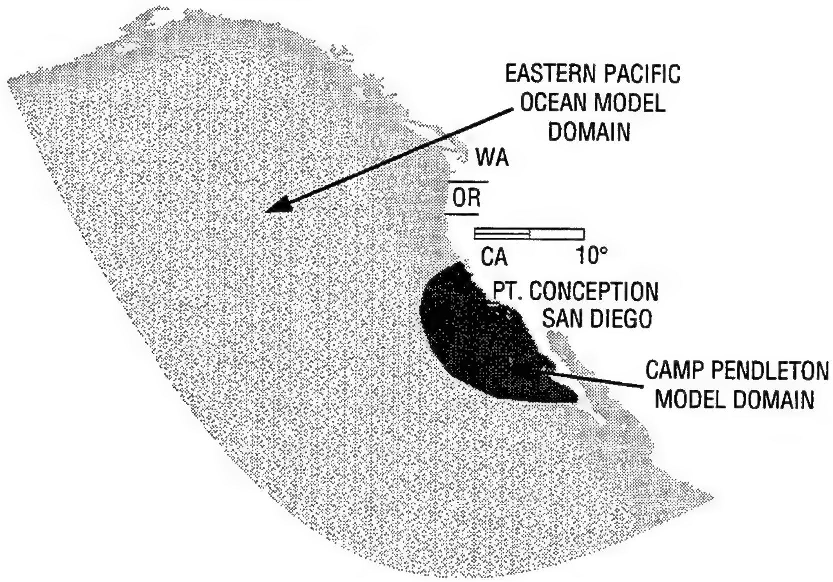

Fig. 6 — Eastern Pacific model domain used to compute tidal boundary forcing at the open boundary of the smaller Camp Pendleton model domain

yields 56 astronomical and nonlinear tidal constituents at the open ocean boundary points of the smaller CAMPP mesh. These tidal amplitudes and phases constitute the open ocean boundary forcing for the real-time ADCIRC-2DDI model forecasts during the JTFEX exercise. Since these boundary conditions are defined in terms of equilibrium tides, their values are obtained prior to a real-time implementation of the ADCIRC-2DDI model. Modifications to the equilibrium tidal amplitudes and phases that reflect conditions on a particular date are accomplished through specification of date-dependent tidal nodal factors and phase equilibrium arguments within the ADCIRC model input structure. These values must be updated within the real-time framework of the model.

2.2.3 Sensitivity Tests

Appropriate preliminary testing of model performance in the region of the exercise includes sensitivity analyses to determine an acceptable duration for model spin-up, specification of the bottom friction parameter, influence of boundary forcing, and stability of the model formulation (e.g., the inclusion of nonlinear terms, wetting/drying of the shoreline, and adequacy of mesh resolution). These tests are an essential component of model implementation. Thorough testing before a new region is modeled is likely to lead to more a stable and accurate real-time, predictive model.

An examination of the required spin-up period for the model was conducted only for the tidally forced model. Ramp periods for wind forcing are generally a day or less whereas shortwave, nonlinear tides are more restrictive in their required spin-up period. Three ramp durations are implemented: 3, 6, and 12 d. Twelve days is considered an optimal length of time for ramp-up of the tidal forcing to eliminate the excitation of any spurious short wavelength energy during a cold model start. For daily forecast runs to complete within a reasonable computational timeframe, a shorter spin-up period is desired; hence, the viability of a 3- and 6-d ramp-up period are examined. Visual inspection of a 24-h time series of forecast elevation, current magnitude, and direction for each ramp-up period of 3, 6, and 12 d (not shown) indicate that the 3-d ramp length produces acceptable forecasts without generating spurious modes; however, during particularly energetic

periods, some numerical noise is evident in the forecast fields. The most notable differences between forecasts using the three ramp durations are instantaneous errors that occur at the time of phase directional changes.

Sensitivity to the coefficient of bottom friction is tested by considering four values ranging over an order of magnitude, 0.0015, 0.003, 0.006, 0.012. Except for model instability caused by a minimal bed friction force produced when using the smallest coefficient, little differences were observed between the computed model solutions for cases involving the remaining three frictional coefficients. The tidal contribution to the dynamics off the southern California coast is known to be relatively small and it is entirely expected that the bottom friction coefficient has a limited influence on the circulation. For the real-time JTFEX predictions, the coefficient of bottom friction is set at 0.003.

A later comparison is made between the open ocean boundary forcing comprised of 56 tidal constituents computed from a simulation of the eastern Pacific Ocean and a limited set of six tidal constituents extracted from the Grenoble data base at the same open ocean boundary points. It turns out that contributions from the additional compound and over-tide constituents to the total elevation are nearly negligible at the CAMPP mesh open boundary. The open boundary location in waters at depths greater than 1000 m minimizes magnitudes of the nonlinear tidal components. While the additional constituents are not needed for forcing the CAMPP model, this strategy for obtaining shelf model boundary forcing from a larger scale model remains a viable and recommended strategy for limited shelf domains.

Though nonlinear tidal contributions in the deep water may be small, they increase in significance in nearshore regions important to the exercise. To fully simulate the nonlinear interactions of the coastal environment, all nonlinearities within the ADCIRC-2DDI model are activated. When the finite amplitude terms (i.e., the ratio of the sea surface gradient to the depth) are included in the model formulation, computational wetting/drying is necessary to maintain model stability. For the JTFEX ADCIRC model application, the wetting/drying option within the model is selected so that the model equations remain both fully nonlinear and stable.

2.3 Implementation

2.3.1 Automation

To fully implement the ADCIRC-2DDI model in a real-time framework, the model setup, execution, post-processing, and display of forecast fields must be automated so as to minimize manpower effort and hands-on interaction during the real-time operation. Before the automatic phase of the model operation proceeds, an appropriate input parameter file (fort.15) for the CAMPP region must be created. The fort.15 file contains switches for a variety of model components that affect the dynamical and numerical configuration, including the activation of nonlinear terms, specification of the frictional coefficient, identification of the form of the wind and pressure forcing, specification of the boundary forcing, and computed field output options. Specifically, equilibrium tides at the boundary point locations and the tidal frequencies forced through the tidal potential are defined initially within the fort.15 input file. The extraction of boundary forcing from an available data base is not part of the automated process, though it could be made so without difficulty. Through the automated procedure, tidal factors and equilibrium phase arguments for the boundary forcing and the tidal potential terms will be updated to reflect the forecast date.

Automation of the ADCIRC implementation for the JTFEX exercise entailed the following tasks: (1) Compute the tide nodal factors and phase equilibrium arguments for the specified forecast

forecast date and latitude of the region, (2) read wind and pressure forcing data, interpolate data spatially to the finite mesh, and formulate the fort.22 wind and pressure forcing file (the fort.22 file contains forcing data for the entire model simulation period at a user-defined time interval), (3) modify the input parameter file (fort.15) with date specific tidal information (changes affect the tidal potential forcing, tidal boundary forcing, and harmonic analysis sections), (4) configure the code for the target machine and dimensions of the problem, (5) compile and execute a 6-d model simulation, and (6) post-process global model fields to eliminate inactive nodal points caused by element drying. The flow chart in Fig. 7 summarizes the entire procedure from preliminary setup, to automation of the model setup, execution, and visualization, and the remaining manual visualization effort involved in using the ADCIRC-2DDI model in support of the JTFEX exercise, July 1997.

2.3.2 Visualization

As part of the real-time run script, model-computed elevation, current magnitude, and direction at 77 stations were selected and are plotted using the *Matlab* software package. Locations of the stations, as depicted on the WWW interface for ADCIRC model products, are shown in Fig. 8a and b. For each station, three time series plots for the 24- and 48-h forecasts are included vertically on the same page such that their time scales are coincident (see examples in Fig. 9a and b for forecasts on 23 and 24 Jul 1997). The units of elevation are in feet and have been adjusted by the mean lower low water level (MLLW) for the month of July. The MLLW value, one for each station location, is computed from a month long tidal simulation. Current magnitudes are in knots and directions in degrees on a 360 scale. Units are chosen to be consistent with the operational NAVOCEANO ADCIRC products.

While creation of time series graphs showing model products at individual points is fully automated, manual post-processing is involved to convert elevation and velocity fields over the entire mesh into hourly contoured snapshots and movie loops for the 24- and 48-h forecast periods using the HYDA graphics software. Three successive zoomed views compensate for the high vector density caused by increasing mesh resolution nearshore. Examples of the contoured ADCIRC model products are shown in Fig. 10a–c for each of the three views presented. The gradation of resolution renders visualization of the entire domain at once rather meaningless. Once the graphic products were generated, manual intervention was needed to launch the script, which packaged and sent all files to the CRAY C90 for transfer to NAVOCEANO and subsequent transfer to the Fleet via a WWW interface.

A portion of the interactive ADCIRC WWW pages consists of a picture of available station locations (Fig. 8). A mouse click on a station retrieves the time series plots of ADCIRC products at that point. As the cursor moves over a station location, coordinates for that station are displayed in the lower left corner of the WWW browser assisting the user in selection of a relevant station. This feature was unique to the ADCIRC WWW pages and was an extremely useful utility. Other ADCIRC model products include contoured hourly snapshots and movies for the forecast day, also available at a click of the mouse.

3.0 ASSESSMENT OF MODEL PERFORMANCE

3.1 During the Exercise

3.1.1 Computational and Manual Effort

Both mesh refinement and bathymetric interpolation were accomplished prior to any ADCIRC model simulations. A fair estimate of the effort required for these tasks was approximately 8 h.

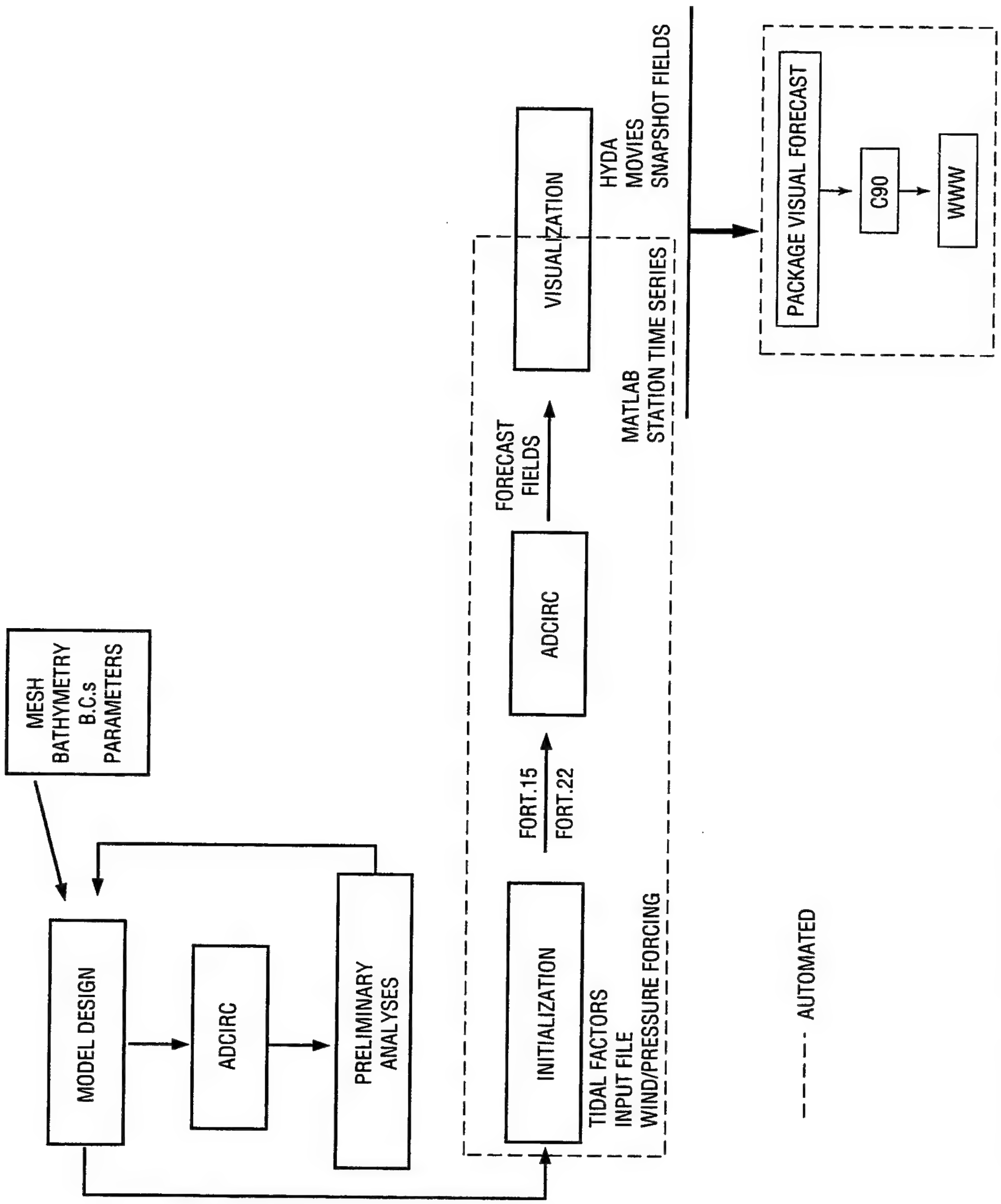

Fig. 7 — A flow chart summarizing the real-time ADCIRC model application off the southern California coast for the JTFEX, July 1997

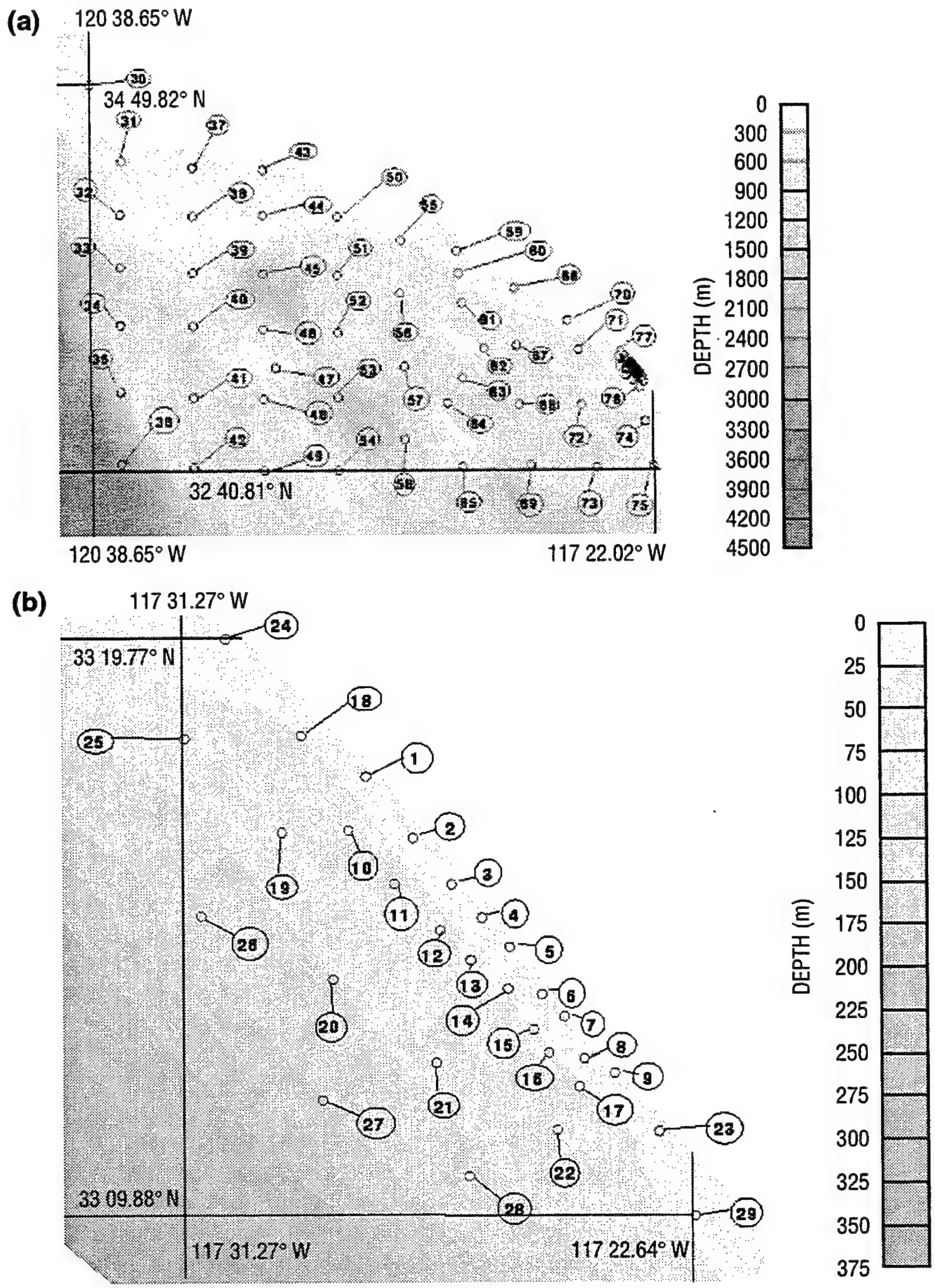

Fig. 8 — The WWW interface depicting station locations (a) over the entire JTFEX region and (b) at nearshore beaches of the exercise. At each station, time series forecasts of elevation and currents are available.

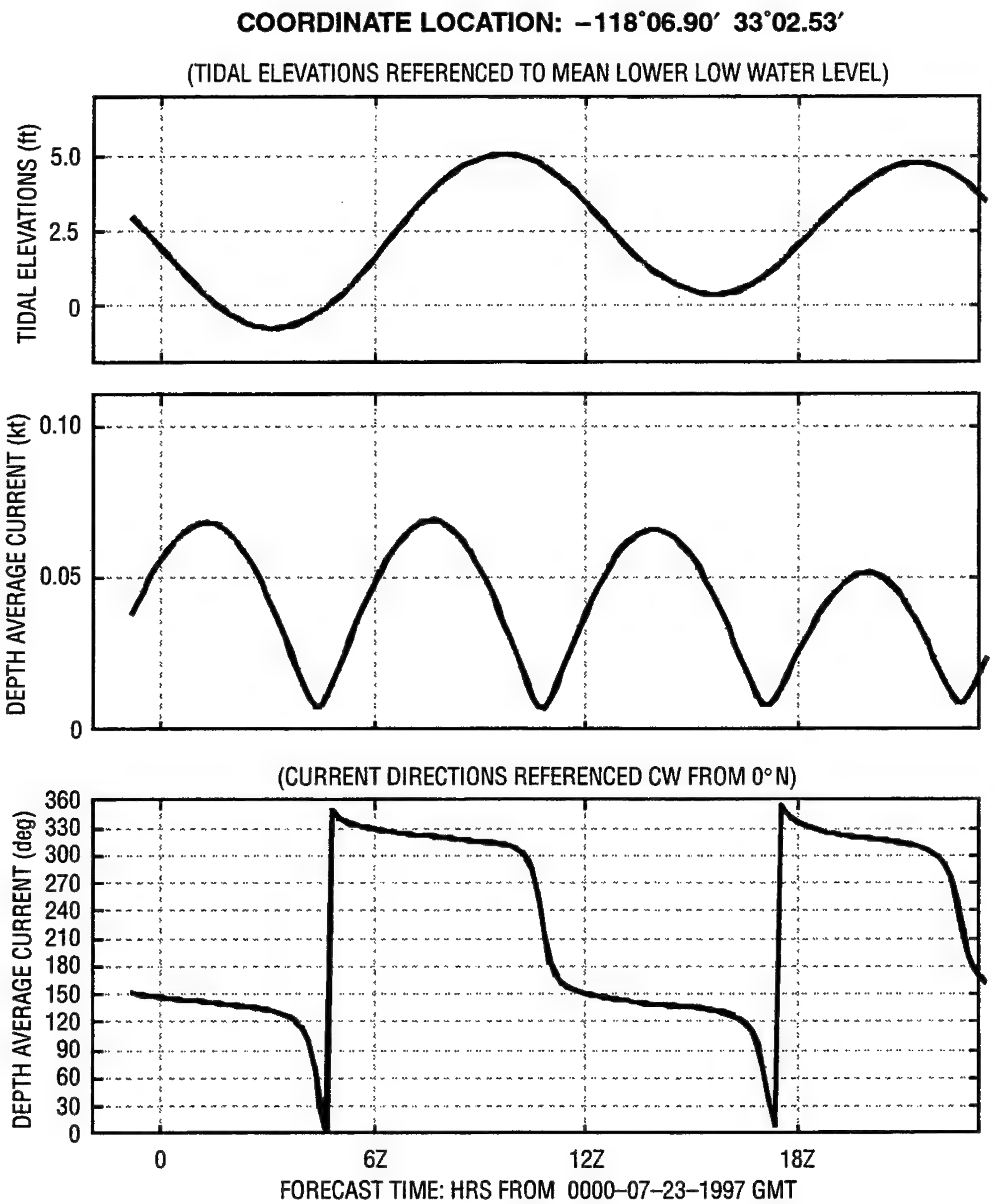

Fig. 9a — Examples of the 24-h forecast fields computed at 77 station locations by the real-time ADCIRC model for 23 and 24 Jul 1997

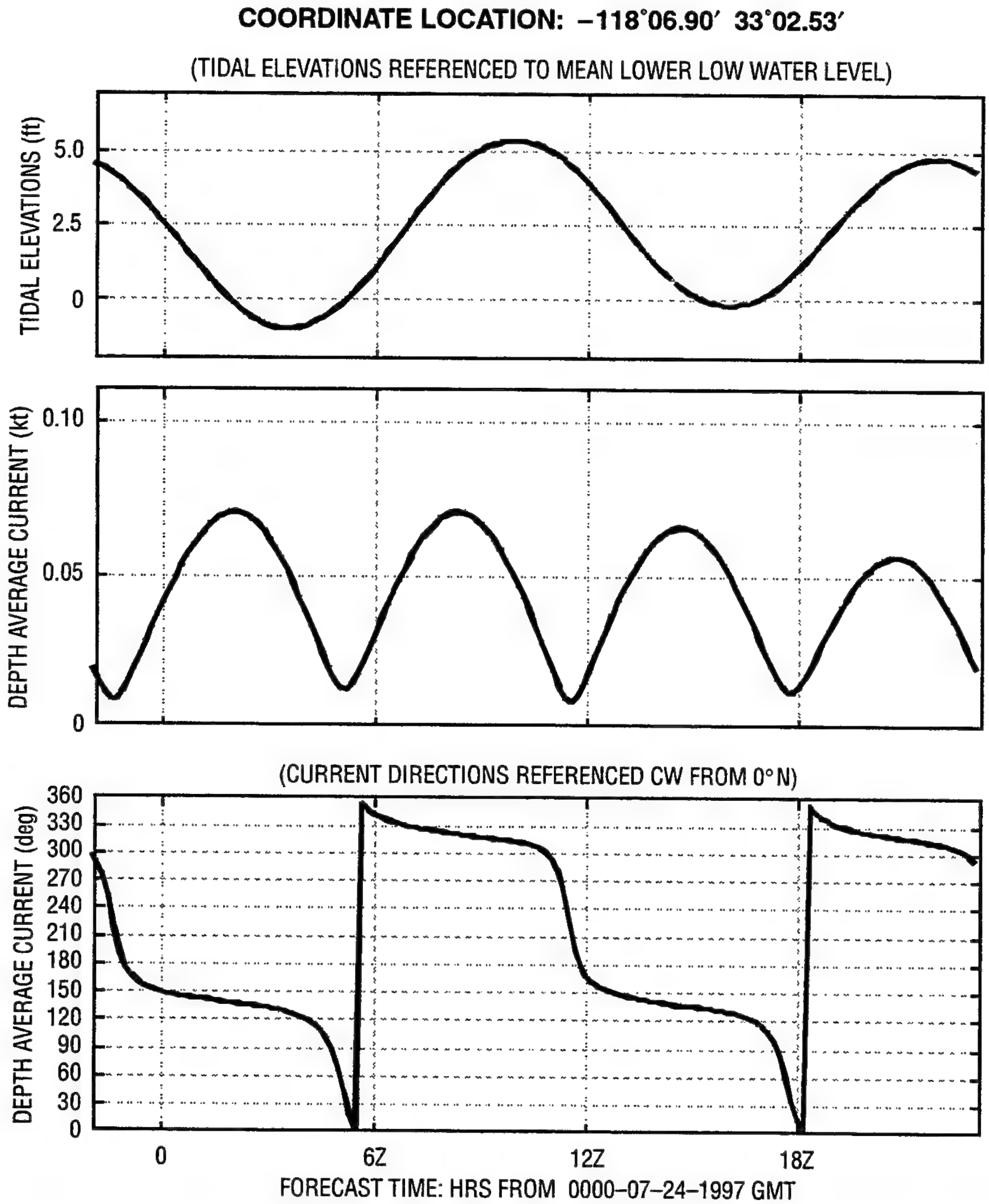

Fig. 9b — Examples of the 48-h forecast fields computed at 77 station locations by the real-time ADCIRC model for 23 and 24 Jul 1997

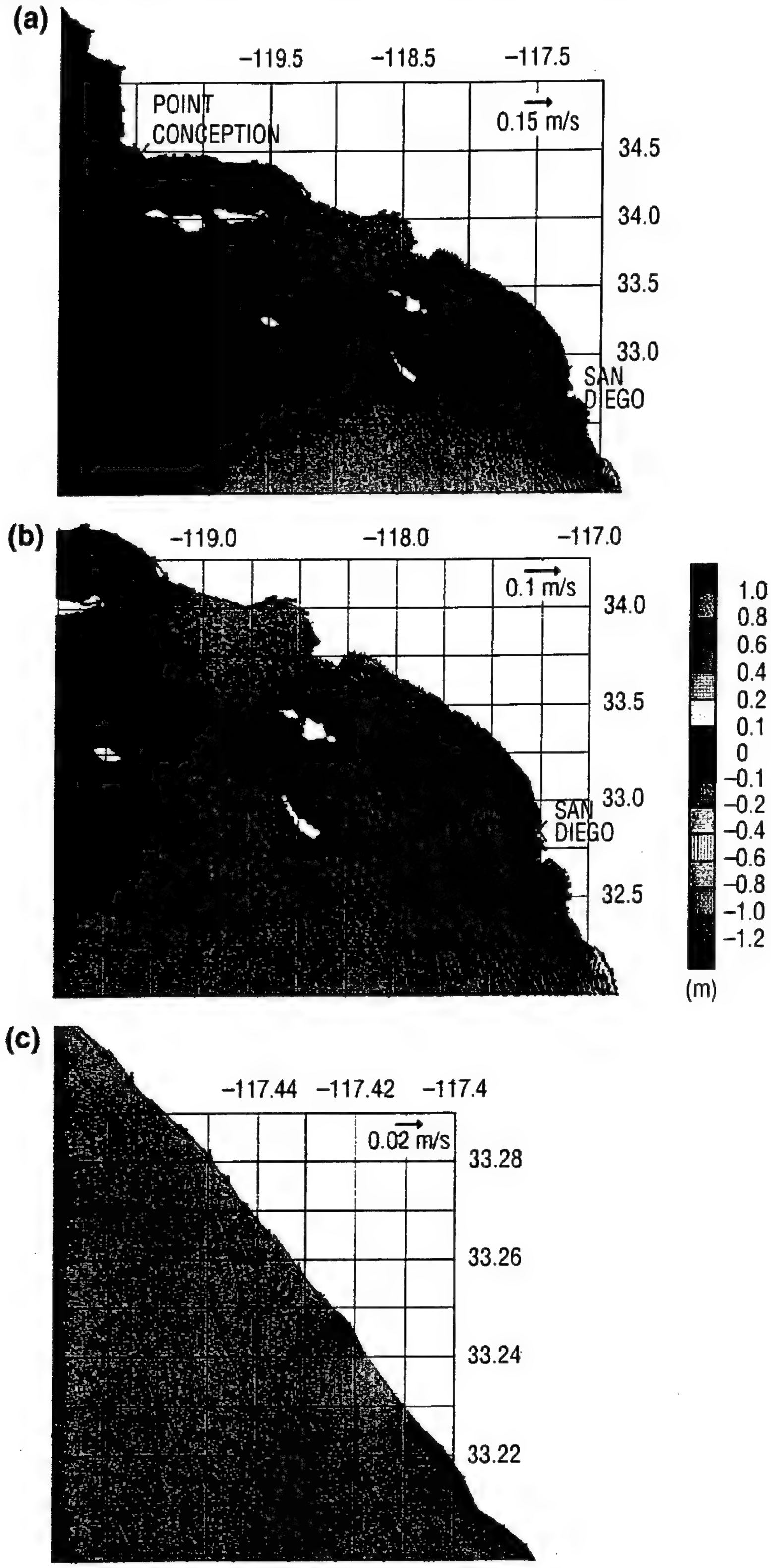

Fig. 10 — Contoured elevation and velocity vector forecasts for 23 Jul 1997 as computed by the real-time ADCIRC model (a) over the entire JTFEX exercise area, (b) nearshore regions, and (c) at Camp Pendleton, CA

Creation of the software that automatically reads and interpolates the surface forcing data and automates setup of the model involved nearly 3 weeks of work. The majority of this effort need not be repeated for new real-time applications due to the general construction of the software. Once the real-time model software was tested and one was reasonably assured that the model itself was configured correctly and model timing was in sync with forcing fields, several weeks were spent running the sensitivity tests previously described.

In addition to the real-time model, a considerable effort was focused on generating useful visual formats for the contoured snapshots and movie loops of elevation and currents and on the development of an informative, interesting, and interactive WWW interface. Experimentation prior to the exercise led to the definition of useful viewpoints, color bars, and other graphical constructs that could be saved within the HYDA software. Once back in HYDA, a graphic parameter file containing this information is recalled to display new forecast fields. In this way, manual labor during the exercise was minimized. Lastly, the construction of scripts facilitating the daily WWW page update and transfer of the WWW model products to a different computer system added to the pre-exercise tasks.

The daily 48-h forecasts for the JTFEX involve a 6-d model simulation. Three days are devoted to model spin-up, an additional day for hindcast, and 2 more days for the actual forecast. For each forecast period, the model was re-initialized from rest. The model discretization is comprised of 6108 nodal points and a time increment of 30 s is used for computation. On a SunSparc Ultra 2 Workstation, the computational effort for the ADCIRC-2DDI model translated into approximately 6 h of CPU time. This time estimate includes all automated reading of the surface forcing files, interpolation of the forcing to the model grid, specification of tidal parameters to reflect a new date, setup of the model code, compilation and execution of the model, and post-processing of the model computed fields using the *Matlab* software to produce time series forecasts of sea surface elevation, current magnitude, and current direction at 77 stations.

Once the computational portion of the real-time model was complete, manual post-processing of the global forecast fields could begin. The manual effort involved using the HYDA software to convert elevation and velocity fields over the entire mesh into hourly labeled and contoured snapshots and movie loops for the 24- and 48-h forecast periods. Additional overhead was incurred to post all model products into a WWW page and package the product for electronic transfer to the CRAY C90 for subsequent transfer to the NAVOCEANO J90 classified system and dissemination to the Fleet. This phase of the real-time exercise ranged from 1–2 h of labor.

3.1.2 Performance

Model predictions during the first 2 d of the exercise produced erroneous results due to an undetected software error in reading and creating the model surface wind and pressure forcing file. Once corrected, periodic checks throughout the remainder of the JTFEX exercise indicated reasonable forecast fields were being computed by the ADCIRC-2DDI model. A Crontab enabled initiation of the real-time model at the earliest possible time after which the NORAPS 0Z wind fields were assumed to be available (approximately 2:00 am CST). By this procedure, the model simulation was near completion at the start of a workday and manual post-processing of the forecast fields could begin. On this schedule, the ADCIRC model product was ready for delivery to NAVOCEANO at approximately 10:00 am CST daily. It would have been possible to issue a timely release of model forecasts initialized by the 12Z NORAPS winds; however, this effort was deemed beyond the scope of the demonstration. It should be noted that the Crontab failed at times when the NORAPS forcing fields were either not available or delayed in reaching the local site. In these situations, construction

of the model surface forcing file required some advance hands-on processing before the real-time model could be manually initiated.

3.2 ADCIRC Model Forecast Fields

3.2.1 Qualitative Evaluation

In general, tidal elevations ranged less than 1 m and nearshore currents averaged approximately 0.1 m/s, well within accepted values for southern California waters (Ramp et al. 1997; Wang 1997). Spurious oscillations in magnitude and direction of the velocity are noticeable sporadically throughout the JTFEX ADCIRC products. The possibility exists that the shortened model spin-up period of 3 d is insufficient in the predominantly wind-driven environment off the California coast. Another source for the numerical noise may stem from the boundary condition specification. Fixed elevations are assigned at the northern and southern cross-shelf boundaries where strong wind stresses are directed parallel to the coast. In prior applications to hurricane storm surge (Blain et al. 1994), elevation specified boundary conditions were adequate, but in those cases, the wind fields developed within the model domain and pushed forward perpendicular to the shoreline.

3.2.2 Comparison to Observed Elevations

Tidal elevations recorded at seven locations along the coast of California during the period from 16–24 Jul 1997 are used to evaluate surface elevation forecasts by the ADCIRC-2DDI model. The source for sea level observations are the moored buoy stations monitored by the National Oceanographic Data Center (NODC) and released by the National Ocean Service (National Oceanic and Atmospheric Administration 1998). At stations along the California coast (i.e., Monterey, Pt. San Luis, Santa Barbara, Santa Monica, Los Angeles, La Jolla, and San Diego), identified in Fig. 11 with respect to the CAMPP model domain, 9 d of computed hourly mean sea level values are compared to observations in Fig. 12a–g. Forecast elevations are taken from the computational model point located nearest a given station; some errors may arise from this inexact comparison.

In all station comparisons a distinctive change in the correspondence of the predicted elevations to the field data occur approximately on or near 20 Jul 1997. After this point in time, model-predicted elevations and observed sea levels are in reasonable agreement. Examination of the wind forcing fields over the course of the exercise indicate that strong daily variance in the winds coincided with the period from 16–19 Jul 1997. This behavior is corroborated upon examination of wind data in the region during the same period. During the period of strong winds, model-predicted elevations show evidence of a surge contribution, which at times masks the generally semidiurnal pattern of the local tidal forced elevations. Table 1 summarizes the root-mean-square (RMS) errors computed at each station for the entire time period. Errors that reflect performance over the duration of the exercise are noticeably skewed by poor model-data correspondence from 16–19 Jul, the period of strong winds. A considerable reduction in the RMS error is seen for a period of rather quiescent winds, 23 Jul 1997. Poor model-data comparisons during strong wind events lend credence to the discussion in Sec. 3.2.1 regarding potential problems with the elevation specified boundary condition for a wind-dominant environment. Furthermore, Blain et al. (1994, 1998) found ADCIRC model computations to be quite sensitive to the magnitude of the wind forcing.

3.2.3 Comparison to NAVOCEANO ADCIRC Products

At the time of the JTFEX exercise, NAVOCEANO had not run the ADCIRC-2DDI model in a real-time framework. Instead, tidal data bases for several regions where finite element model

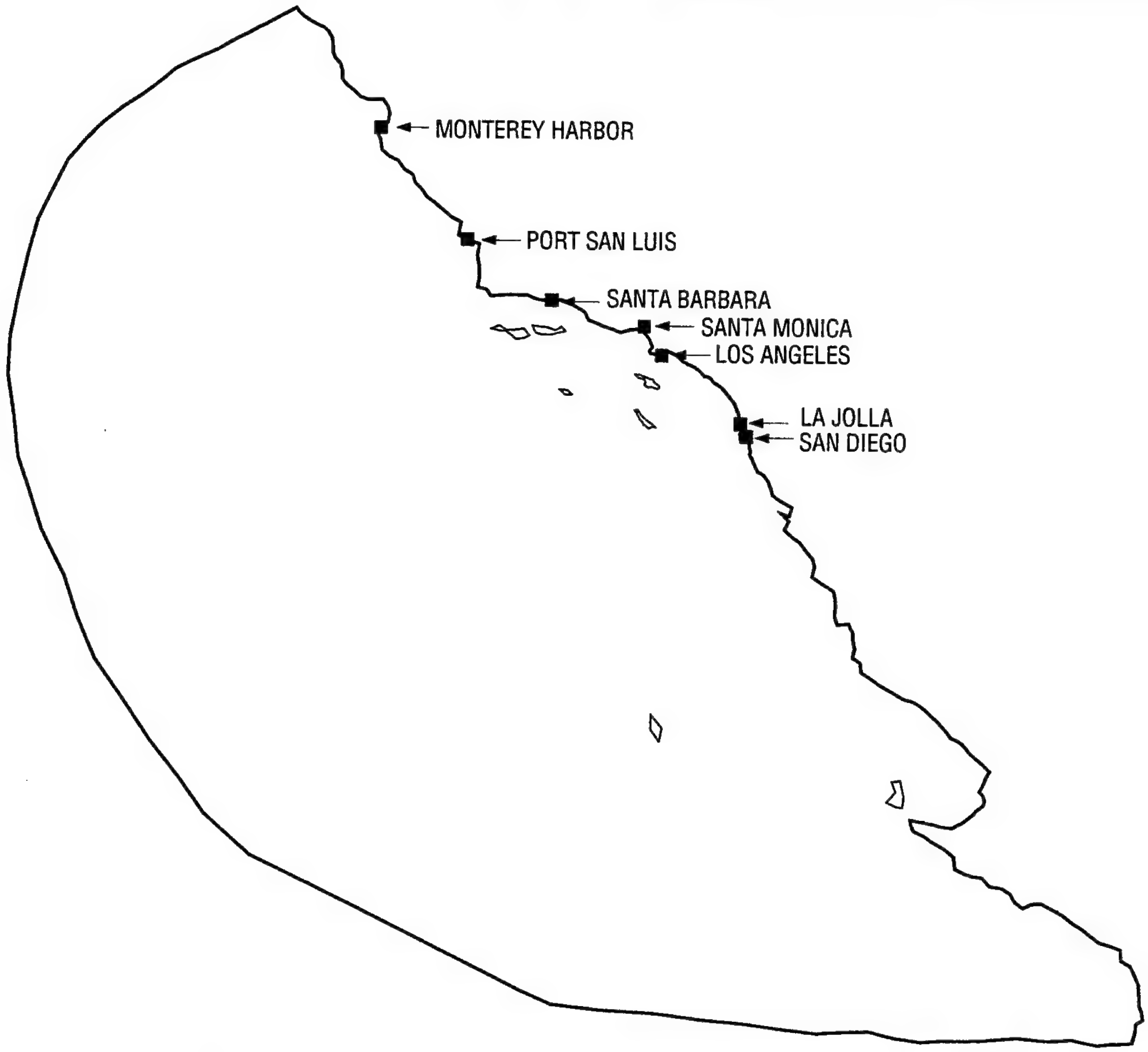

Fig. 11 — Locations of seven NODC observational water level stations

meshes exist have been produced by the U.S. Army Corps of Engineers at the Coastal Engineering Research Center (Westerink et al. 1993). The tidal data base for the SOCAL region was likely constructed from a 30-d run of the ADCIRC-2DDI model subject to tidal forcing only. A harmonic analysis of this 30-d run produces eight primary tidal constituents, M_2, S_2, N_2, K_2, K_1, O_1, P_1, Q_1. It is the equilibrium amplitudes and phases of these constituents that are stored into the tidal data base. Time series of elevation and depth-averaged velocities are then reconstructed from the data base at user-specified locations for user-specified time periods. All of this analysis can be done a priori, that is, no real-time component exists for this prediction.

A downside to this approach is that wind effects are not included. Furthermore, since the model is not being run, no new information regarding bathymetry, shoreline coordinates, or advances in the model itself may be incorporated into the forecast model. Refinement of the mesh to address the resolution requirements of a particular exercise is also not possible using a data base approach. Clearly, implementation of a hydrodynamic model in real time requires considerably more effort prior to simulation for each new application, e.g., setting up the model, refining the mesh, updating

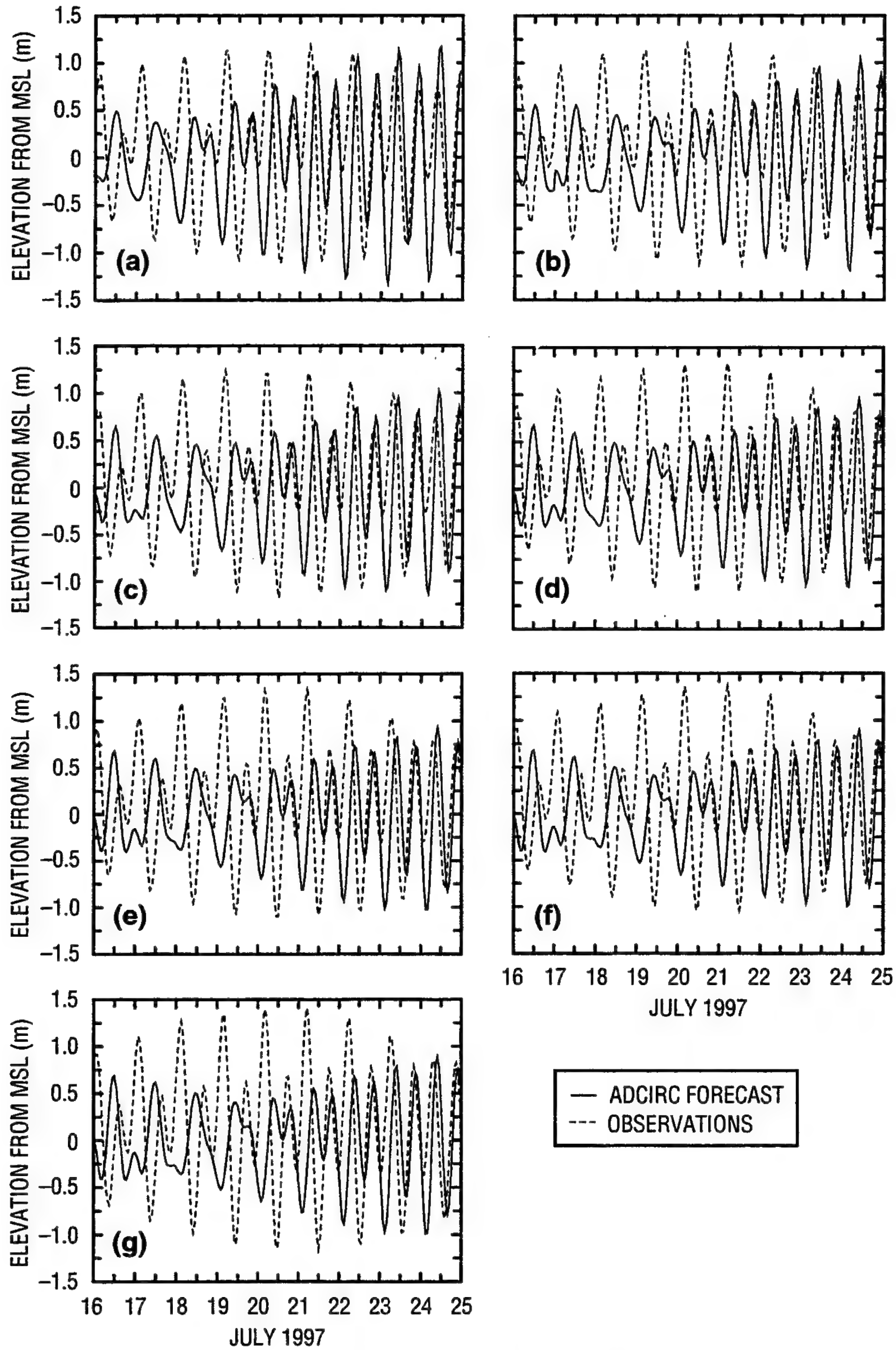

Fig. 12 — Comparisons between ADCIRC model-predicted water levels and NODC observations from 16–24 Jul at (a) Monterey, (b) Pt. San Luis, (c) Santa Barbara, (d) Santa Monica, (e) Los Angeles, (f) La Jolla, and (g) San Diego, CA

Table 1 — RMS Errors for ADCIRC Model Forecasts at Seven NODC Stations Along the Southern California Coast for the Period 16–24 Jul 1997

STATION	LOCATION LAT, LON	MODEL NODE	RMS ERRORS (m) 16–24 JUL	RMS ERRORS (m) 23 JUL
Los Angeles	33.72° N, 118.272° W	5149	0.834704	0.246092
La Jolla	32.867° N, 117.256° W	2829	0.824866	0.243672
Monterey	36.605° N, 121.883° W	5878	0.832252	0.244325
Pt. San Luis	35.1766° N, 120.76° W	5614	0.775643	0.214045
San Diego	32.713° N, 117.173° W	2413	0.841543	0.244814
Santa Barbara	34.408° N, 119.685° W	5451	0.835620	0.244988
Santa Monica	34.008° N, 118.5° W	5267	0.833693	0.249662
		Mean	0.825474	0.241005

data bases, and testing model performance in the region. However, relevance of the forecasts from such a model far outweigh this investment of time.

A reconstructed NAVOCEANO ADCIRC model product is compared to the NRL ADCIRC products and notable differences are evident, even for comparisons to NRL simulations that are strictly tidal forced. Velocities in particular show considerable variance. Examples of these comparisons on 23 Jul 1997 are presented at four station locations (20, 68, 44, and 41) in Fig. 13a–d, respectively. The exact source of the discrepancy remains unknown. One possibility is that reconstructed NAVOCEANO fields may be shifted in time with respect to the NRL computed fields; for tidal forecasts, this difference would be significant. Secondly, it is known that a 30-d period for the harmonic analysis of the eight constituents listed in the NAVOCEANO tidal data base is insufficient to accurately separate the frequencies of these constituents. Recall also that the NAVOCEANO base grid is much coarser in resolution in nearshore areas than the grid used for the NRL forecasts. Both of these factors may contribute to discrepancies in the tidal current predictions.

4.0 RECOMMENDATIONS AND DIRECTIONS

4.1 Changes to Model Implementation

A restart option within the ADCIRC-2DDI model will remove the necessity of a daily model spin-up period and eliminate any computational irregularities imposed by the shortened 3-d ramp period applied during the JTFEX exercise. Using the model's existing hot-start feature is one possible solution for achieving a restart capability for the ADCIRC model. This form of restart

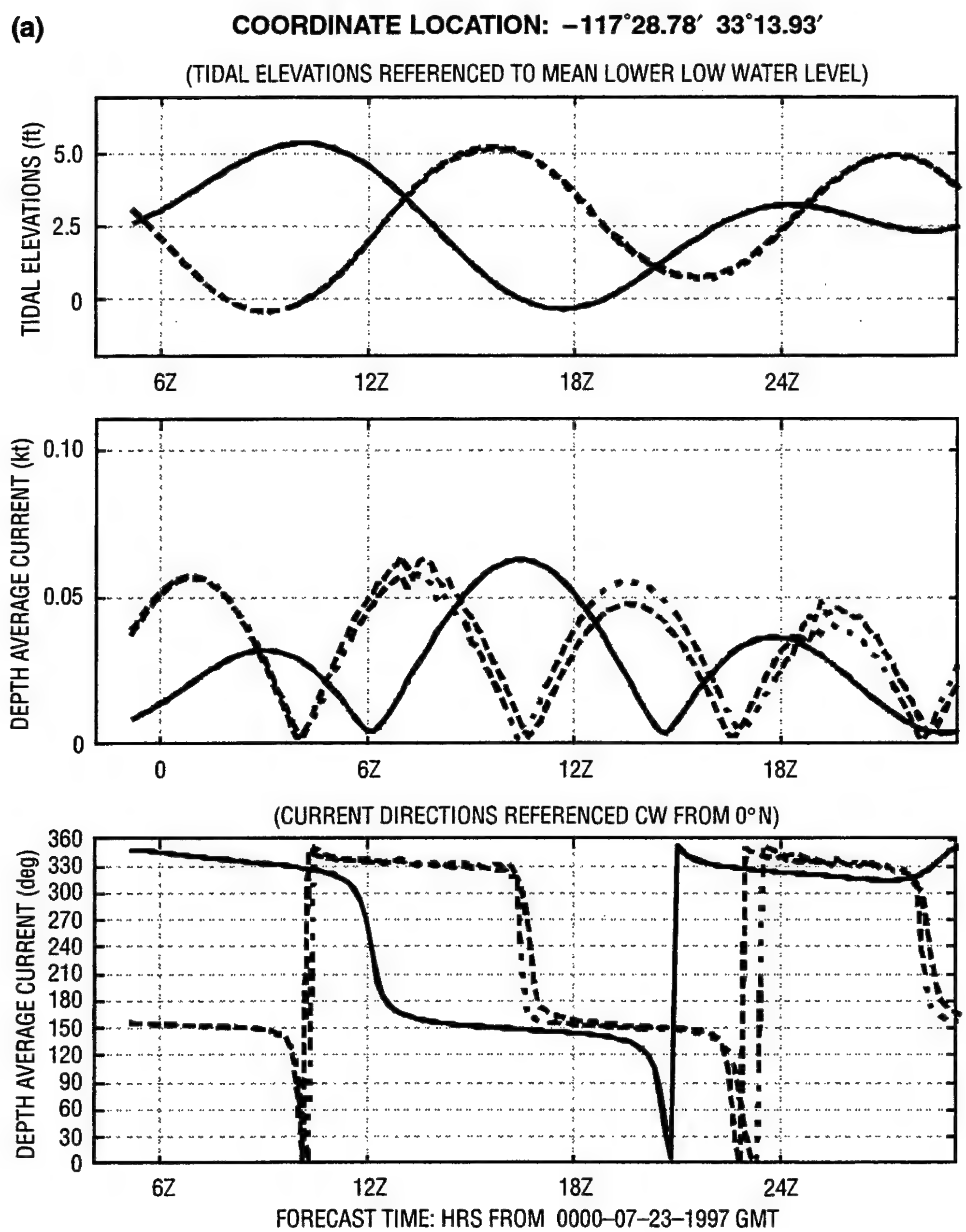

Fig. 13a — Comparisons between reconstructed NAVOCEANO ADCIRC products (solid line) and the NRL JTFEX products (dashed line = tide and wind forcing, dotted line = tidal forcing only) for 23 Jul 1997 at station 20

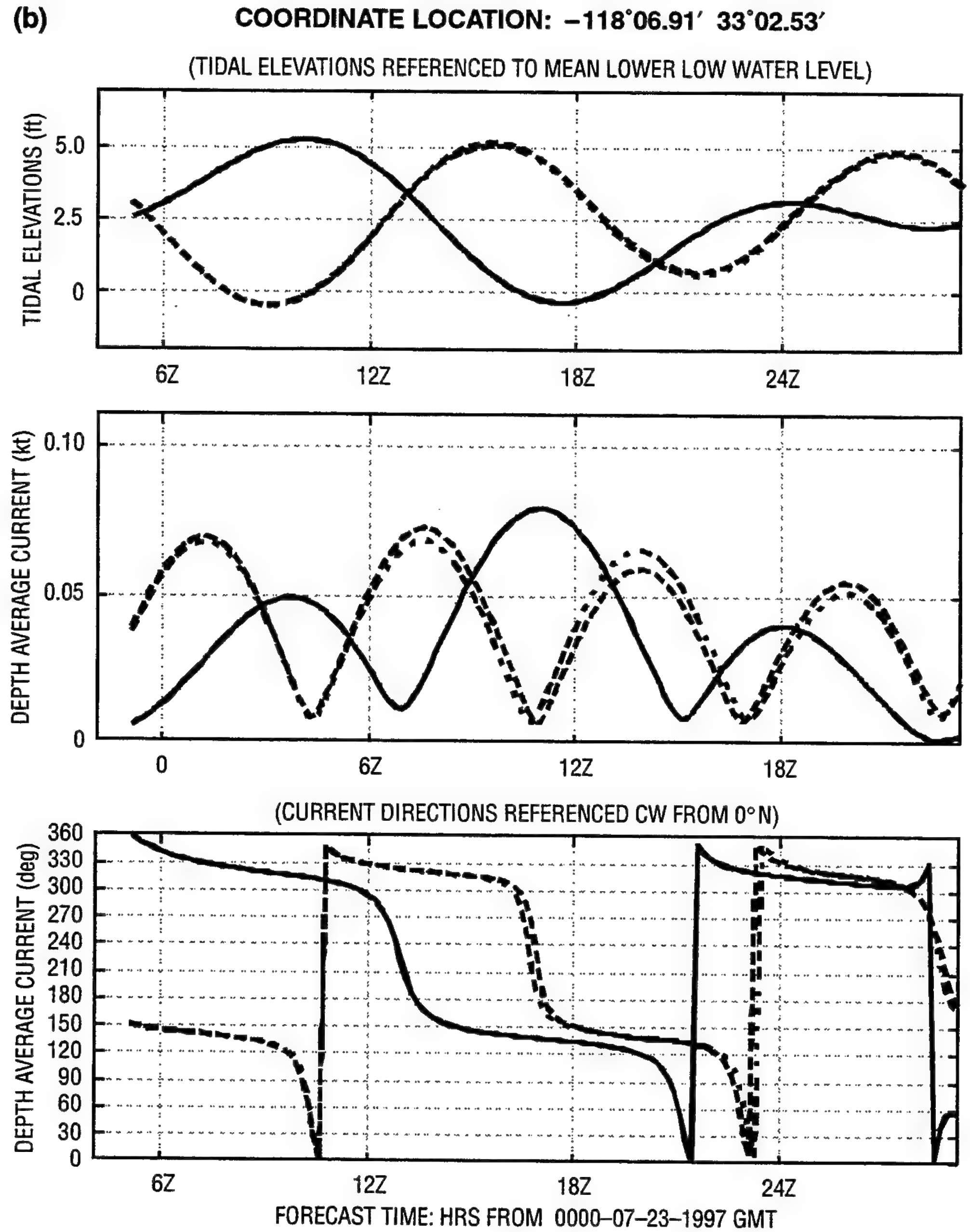

Fig. 13b — Comparisons between reconstructed NAVOCEANO ADCIRC products (solid line) and the NRL JTFEX products (dashed line = tide and wind forcing, dotted line = tidal forcing only) for 23 Jul 1997 at station 68

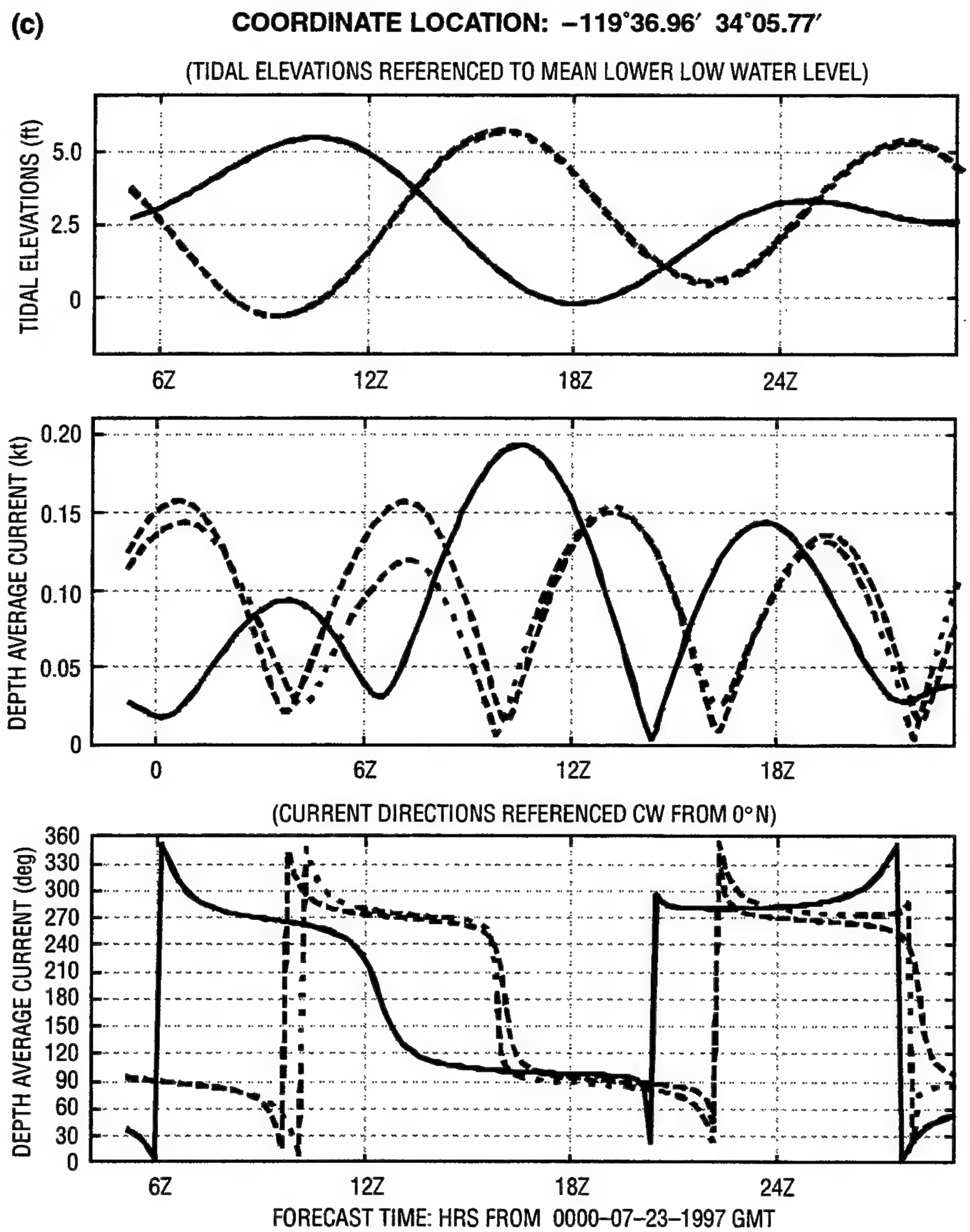

Fig. 13c — Comparisons between reconstructed NAVOCEANO ADCIRC products (solid line) and the NRL JTFEX products (dashed line = tide and wind forcing, dotted line = tidal forcing only) for 23 Jul 1997 at station 44

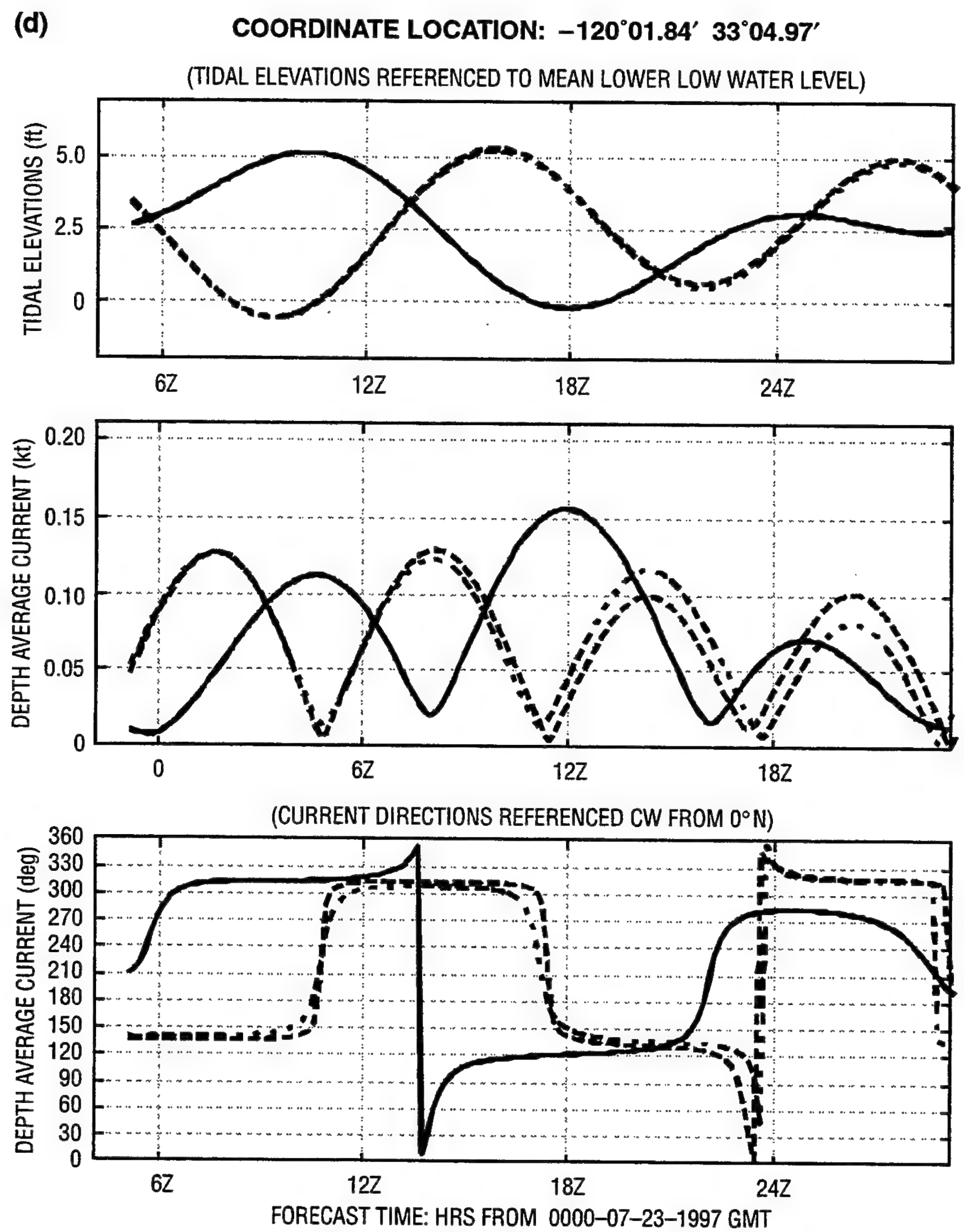

Fig. 13d — Comparisons between reconstructed NAVOCEANO ADCIRC products (solid line) and the NRL JTFEX products (dashed line = tide and wind forcing, dotted line = tidal forcing only) for 23 Jul 1997 at station 41

will require careful modification to the input parameter file, fort.15. A brief study is necessary to detail implementation of the hot-start feature as a restart option. For a model that has a restart capability, an extensive spin-up of the model can be completed before real-time predictions begin. A hot-start file containing model fields and parameters written at the end of the spin-up period provides the model restart conditions. Forecast simulations then commence using the restart fields for initialization, eliminating any artifacts of a truncated spin-up period as well as additional computational time associated with duration of the ramp.

A glaring need for software capable of merging multiple sources of bathymetry and/or wind and pressure forcing fields emerged during the preparatory phases of model setup for the exercise. Such a capability must be developed and tested; software having a modular interface that accepts a variety of data fields at varying resolutions and merges the data and interpolates to regular or variably graded grids is ideal. Such a capability is necessary to utilize available sources of high-resolution fields in a specified region without resorting to hand techniques or compromising model bathymetry or forcing fields by using crude methods. While some software may be currently available to accomplish this goal, it is unlikely to accommodate unstructured data.

For the JTFEX exercise, the selection of an elevation open boundary forcing was made prior to any knowledge of the dynamics in the region. This would not be uncommon in a true rapid response scenario. However, in the strongly wind-driven environment off the California coast, these boundary specifications appear inadequate and other options should be entertained. For the elevation open boundary conditions used for the exercise, values of the tidal amplitudes and phases are specified as part of the preliminary model construction and are not included within the automated model setup. Future real-time prediction systems may wish to incorporate an automated extraction of the boundary elevations within the real-time script and setup of the ADCIRC model.

Other improvements to a real-time implementation of the ADCIRC-2DDI model would include a mechanism to automatically handle periods in which the wind and/or pressure forcing is unavailable. If 0Z wind and/or pressure fields used during the exercise are missing for either the hindcast or forecast periods, the model will not successfully execute without user intervention to create wind and/or pressure fields for the missing days. Furthermore, software that accommodates alternative sources of wind and pressure forcing is needed; the capability of using either wind velocity or wind stresses as forcing would also be useful. Lastly, a standardized format for the FNMOC wind and pressure fields would greatly simplify the automated preprocessing of these data fields for forcing; the standardized format applies to the data itself and to the time intervals of the data.

4.2 Changes to Model Products

One of the primary advantages of finite element models is the variable resolution, unstructured meshes that allow for more realistic representations of steep bathymetric gradients and coastline detail. Visualization tools that specifically handle the irregularities of unstructured data are in their infancy and are not configured to execute in a batch framework. Thus, considerable effort was spent manually obtaining color-contoured graphics of the model-predicted fields. To utilize graphic tools that accept regularly gridded data, finite element model products must be interpolated to very fine resolution regular grids or the advantage of highly resolved forecasts in localized regions is lost. For those graphic packages that directly map to the finite element mesh, a means to sub-sample vectors is necessary to produce clear and easily interpreted pictures. Overall, the experience of the JTFEX further emphasized that the visualization of finite element model fields has room for considerable improvements and advances.

The framework for release of the ADCIRC model real-time forecast products is a WWW page. The WWW page design is visually appealing, branching out to various model products and information about the model itself. Movie clips of the predicted elevation and current fields are thought to be an excellent means for interpreting the ADCIRC model products. Within the research environment, it is common and often more instructive to view an animated forecast field than single snapshots in time. While both mediums were provided, feedback from Navy personnel using the JTFEX products indicated that complexity of the WWW page, large file sizes associated with the movie clips, together with the lack of a universal movie player rendered the ADCIRC products less useful. The visual presentation of coastal circulation model forecasts needs some rethinking in terms of how the Navy will use such products and what types of information they actually utilize.

Aside from traditional model products, statistical analyses providing mean, maximum, and minimum values, their locations, and other types of information should be included as it is warranted by the Navy user community. In addition to the model-computed fields of elevation and currents, the wind and pressure fields applied as forcing to the model should also be included with the model products for both monitoring and interpreting the forecasts.

4.3 Transitions

At a meeting 28 Aug 1997 between NAVOCEANO and NRL personnel, plans were formulated for a rapid transition of the preprocessing software and scripts pertaining to automation of the ADCIRC-2DDI model setup and real-time execution. The transitioned ADCIRC model is forced by surface pressure, surface wind stress, tides at the open ocean boundary, and tidal potential on the interior. The model is configured to accommodate the wetting and drying of computational points. Included as part of this transition are programs to compute date and latitude dependent tidal nodal factors and phase equilibrium arguments, to read and interpolate the NORAPS wind velocity and pressure fields to the finite element mesh, and to generate a daily input parameter file for the ADCIRC model forecast simulation. A routine that automatically extracts tidal boundary forcing from the Grenoble global tidal model is also included in the transition. Appendix A contains the official letter detailing the transition of October 1997.

5.0 ACKNOWLEDGMENTS

We would like to thank Joshua Dickinson for development of the World Wide Web page interface and Dan Fox for his efforts in transferring our JTFEX product to NAVOCEANO. This work has been funded by the Office of Naval Research through the NRL 6.2 Coastal Simulation project (Program Element number 0602435N).

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Appendix A

DOCUMENTS PERTAINING TO THE TRANSITION TO NAVOCEANO

DEPARTMENT OF THE NAVY

NAVAL RESEARCH LABORATORY
4565 OVERLOOK AVE SW
WASHINGTON DC 20375-5320

IN REPLY REFER TO

6 OCT 97

From: Commanding Officer, Naval Research Laboratory
To: Commanding Officer, Naval Oceanographic Office

Subj: Rapid Transition of Prototype ADCIRC Model Real-Time Execution Utilities

Re: (a) NAVOCEANO Ser OT /90103651 of 9 Nov 1994
(b) 27 Aug 97 Meeting of George Mason, Paul Rivera (NAVOCEANO) and John Harding, Ruth Preller, and Cheryl Ann Blain (NRL)
(c) 22 Sep 97 e-mail from Tom Curtin (ONR) to John Harding (NRL)
(d) 16 Sep 97 e-mail from Steve Payne (SPAWARSYSCOM) to John Harding (NRL)

Encl: (1) Definition of ADCIRC Real-Time Execution Utilities Transition

1. The Naval Research Laboratory (NRL) Ocean Dynamic and Prediction Branch developed and demonstrated a real-time run capability using the finite element hydrodynamic model ADCIRC-2DDI as part of the JTFEX at Camp Pendleton, CA 14-25 July, 1997. This capability provides real-time coastal barotropic currents and sea surface height forced by surface pressure winds and tides. The Naval Oceanographic Office (NAVOCEANO) does not currently exercise the ADCIRC-2DDI model in this real-time operational mode but relies on regional tidal data bases generated by a single tidally-forced ADCIRC model forecast.

Under the auspices of the NRL/NAVOCEANO Coastal Modeling Memorandum of Agreement (encl. 1 of ref (a)) and based on NAVOCEANO/NRL discussions (ref. (b)) and the direction and strong endorsement by ONR (ref. (c)) and SPAWAR (ref. (d)), we propose a rapid transition of this real-time capability to the NAVOCEANO Warfighting Support Center. The proposed transition will allow automated, real-time forecasts of tidal and wind-driven circulation using the ADCIRC-2DDI model for the

Camp Pendleton area. The general design of the software allows NAVOCEANO personnel to subsequently apply the ADCIRC real-time predictive capability to strategic regions where finite element meshes already exist such as the Yellow Sea, Sea of Japan, Persian Gulf, Mediterranean Sea, and the east coasts of the U. S.

2. Enclosure (1) details the software to be transitioned and the level of assistance to be provided by NRL to NAVOCEANO.

3. NRL point of contact is Dr. Cheryl Ann Blain (228) 688-5450.

WILLIAM B. MOSELEY

By direction

Rapid Transition of Prototype ADCIRC Model Real-Time Execution Utilities

Programs and scripts developed by the Naval Research Laboratory to automate the setup and execution of the ADCIRC-2DDI shallow water finite element model will be rapidly transitioned to NAVOCEANO for operational implementation. Sufficient documentation of program usage is contained within each code comprising this rapid transition. No further external documentation will be provided since this effort at present is unfunded and is intended to efficiently enhance the current operational capabilities at NAVOCEANO.

Outlined below are the transitions and the level of NRLSSC support associated with these transitions.

Transition	**Performer**	**Date**
2. ADCIRC Operational Run script used for the Camp Pendleton JTFEX	NRLSSC	Nov, 1997
3. Code to compute time dependent tidal factors	NRLSSC	Nov, 1997
4. Code to read and interpolate NORAPS PT. MUGU wind velocity and pressure fields to the finite element mesh and write out as input to the ADCIRC model	NRLSSC	Nov, 1997
5. Code to modify the ADCIRC model input file (fort.15) for wind and date dependent tidal forcing	NRLSSC	Nov, 1997
6. Fortran and Matlab code which automates station plotting of environmental variables	NRLSSC	Nov, 1997
7. Global tidal data from the Grenoble model	NRLSSC	Nov, 1997
8. Code to extract tidal forcing for the open ocean boundary from the Grenoble data	NRLSSC	Nov, 1997
9. Real-time example at Camp Pendleton	NRLSSC	Nov, 1997

Support	**Performer**	**Date**
Verbal Instructions on usage	NRLSSC	Nov, 1997

The above software transitions will be completed in one meeting with NAVOCEANO. At this time NRLSSC will provide detailed verbal instructions on implementation and any known limitations of the software.

Assistance in the form of verbal consultation will be provided to facilitate modifications of the software so that NAVOCEANO can implement ADCIRC operationally in another geographic region of interest.